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A Transportable High-Resolution Gamma-Ray Spectrometer and Analysis System Applicable to Mobile, Autonomous or Unattended Applications

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A TRANSPORTABLE HIGH-RESOLUTION GAMMA-RAY SPECTROMETER AND ANALYSIS SYSTEM APPLICABLE TO MOBILE, AUTONOMOUS OR UNATTENDED APPLICATIONS

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ABSTRACT

The Safeguards Technology Program at the Lawrence Livermore National Laboratory is developing systems based on a compact electro-mechanically cooled high-purity germanium (HPGe) detector. This detector system broadens the practicality of performing high-resolution gamma-ray spectrometry in the field. Utilizing portable computers, multi-channel analyzers and software these systems greatly improve the ease of performing mobile high-resolution gamma-ray spectrometry. Using industrial computers, we can construct systems that will run autonomously for extended periods of time without operator input or maintenance. These systems can start or make decisions based on sensor inputs rather than operator interactions. Such systems can provide greater capability for wider domain of safeguards, treaty verification applications, and other unattended, autonomous or in-situ applications.

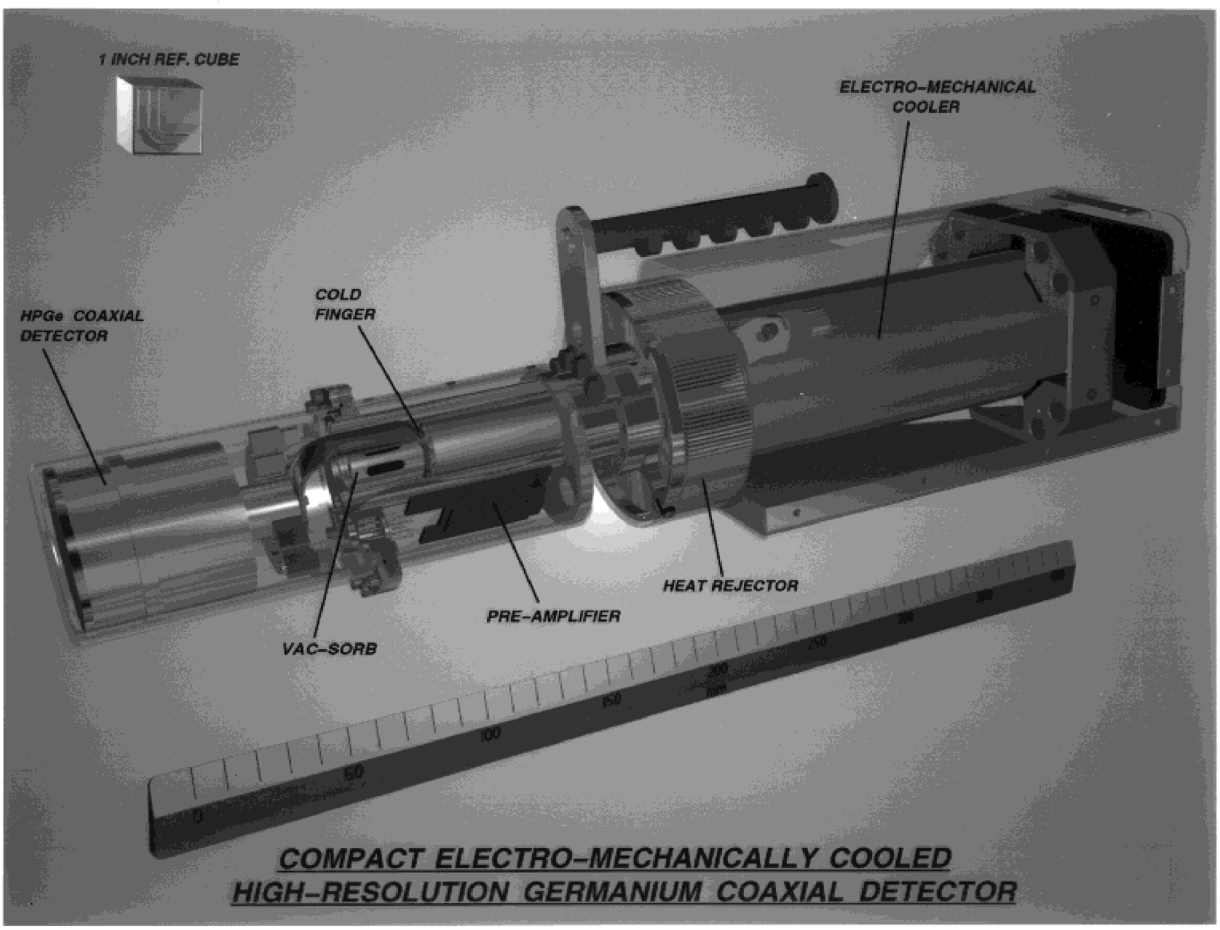

Figure 1

INTRODUCTION

The use of germanium detectors in applications requiring high-resolution x- or γ-ray spectrometry is widespread. There are a number of applications, growing in importance, for which high-resolution x- or γ-ray spectrometry would be very useful, but is not considered practical. This is primarily because the cooling requirements of the germanium detector create logistic and/or technical constraints that limit the applicability of germanium detectors in certain situations. Kenneth Neufeld and Wayne Ruhter of the Isotope Sciences Division at LLNL, with support from DOE's Office of Research and Development (NN-20), have developed an electro-mechanically cooled germanium detector that obviates most of those constraints. This opens a number of applications to solutions based on high-resolution x- or γ-ray spectrometry.

For portable or field applications, the level of portability is increased with the cryo-cooled HPGe detector because there is no need to procure sources of LN_2. For unattended applications using a germanium detector without our cryo-cooler, either a source of LN_2 and technical support for filling or tending an automated fill system, or technical support for an existing commercial refrigeration system would have to be available. Additionally, for some unattended (or in-situ) applications venting of the nitrogen boil-off could be a problem.

Software for portable or unattended applications has some different requirements than data acquisition and analysis software designed for laboratory use by scientists.

For portable applications, simplicity and ease of use and calibration are a high priority. Intelligent data acquisition that quality assures the data in near real-time and self-diagnosing analysis software improve quick assessment of the adequacy of field measurements.

Unattended applications are also improved by the features listed in the preceding paragraph. They also need software that requires no operator intervention or maintenance, can adapt to some situations and report other off-normal situations, and make operational and analysis decisions based on sensor inputs rather than operator inputs.

ELECTRO-MECHANICAL COOLING

There are several technologies that are alternatives to liquid cooling. High pressure gas systems share two of the limitations of liquid cooling in that a source of gas need to be available and they require venting. Conventional large-scale electro-mechanical coolers are bulky, microphonic and cannot be expected to run for more than a few months without maintenance. Stirling cycle cryo-coolers offer size and power consumption advantages, but are also microphonic and can only be expected to run for a few months.

Refrigeration advances, driven by infrared imaging applications, are available with small packages and longer anticipated lifetimes (~10 years). The microphonics are still an issue and have been addressed several different ways. Two passive techniques are employing additional mass to absorb the vibration or using complicated mounting schemes to decouple the vibration. One can also actively cancel the vibration. This is the technique we are using.

We are using a Sunpower cryo-cooler. The specific advantages of this cooler result primarily from the gas-bearing design of the cold-head which improves reliability, vibration and lifetime. This cooler has an integrated counterbalance mass and electronics to perform high-speed vibration control using DSP (digital signal processing) technology (see Figure 2). We have achieved a significant reduction in vibration with overall acceleration levels reduced from greater than 1 g to ~1-10 mg. The most straightforward measure of the effectiveness of the vibration cancellation is the detector resolution. This shown in the performance section in Table 1.

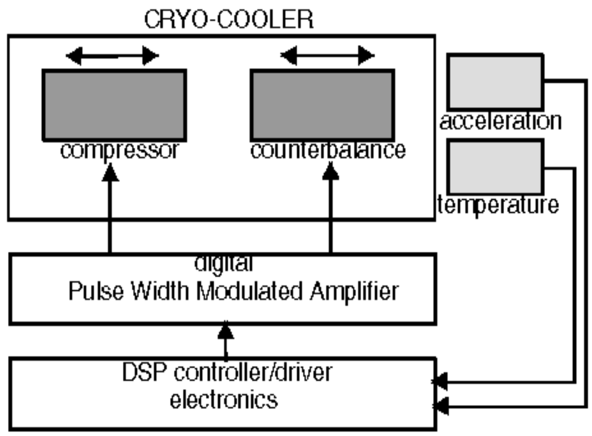

Figure 2. Active Vibration Control

SYSTEMS DESIGN

Portable, unattended measurement systems have many common requirements. Size, weight, and power consumption are important to portable, most embedded and some unattended applications. Long lifetime and reliability are important to unattended and desirable for portable applications. Computer controlled multi-channel analyzer (MCA) and analog electronics are necessary for unattended systems and desirable for most others so that calibration can be automated and the system can adapt easily to changes in the samples or sampling environment.

Current MCA hardware that meets the above requirements include the *InSpector* from Canberra Nuclear Products Group, the *SpectrumMaster 92X*™ and *Nomad*™ from EG&G Ortec, and the M^3CA from Aquila Technologies/LANL.

There is also considerable overlap in software requirements. Unattended and some portable systems require autonomous operation. Autonomous systems will not have a user interface, except perhaps for a diagnostic mode. They will make operational and analysis decisions based on external sensor values or analysis of the spectral data. They also need to be able to monitor their environment (power, temperature, detector performance, and facility, package or sensor integrity) to determine the viability of measurements.

Because of distractions and other limitations of field measurements, operator attended systems need to have a simple and direct user interface and straightforward operation. They may have many of the decision-making capabilities of autonomous systems, but can express them as recommendations or notices to the operator. Operators can have a wide range of technical backgrounds. The instrument needs to assist the operator by automatically changing or suggesting changes to the measurement parameters, when possible, and displaying notifications or expert suggestions to the operator in an easy to understand form. This will decrease the setup time for data acquisition, reduce the need for operator training, and improve operation of the system for assurance of spectral data quality and results. The objective is to improve the quality of gamma-ray spectral data by using computer-controlled electronics and software that monitors the quality of the data in real-time to automatically modify measurement parameters or to notify the operator to change the measurement conditions. These 'intelligent' features will enable operators to have portable instruments for field measurements that can obtain reliable and consistent information in a wide variety of conditions.

All fielded systems benefit from fail-soft operation (no system hangs or application crashes without an automatic restart). This feature is essential for unattended systems.

Analysis software requirements vary with the application and transparency or other constraints. We are building an analysis architecture that can be adapted to a wide variety of analysis applications. *MGA++* [1,3] is designed from a variety of modules or tools that can be assembled on the client-server model. This model requires support for multi-tasking. This eliminates *MS-DOS*™ and also *Windows*™ as operational computing environments. *Windows 95*™, *Windows NT*™, *Unix*™ and *OS/2*™ remain as options for small systems.

DETECTOR SYSTEM SPECIFICATIONS

Size *length 56 cm and diameter 13.7 cm (for LEGe)*

Weight *less than 6.8 kg (detector and cryo-cooler)*

Power Requirements

consumes 37-97 watts

(8-12 hours of battery operation with 11.4 kg Ni_Cd batteries)

Cooling Capability

4.25 watts of lift @ 77°K, cool-down for a LEGe ~3-4 hours and cool-down for a 50% HPGe ~ 6-8 hours

LEGe DETECTOR SYSTEM PERFORMANCE

Durability

continuous operation, expected Mean-Time-To-Failure (MTTF) is 5-10 years

prototype system has operated more than 5000 hours, through more than 200 power and temperature cycles

Temperature Stability

± 0.5°K at 78°K

Resolution [5]

Isotope	LN_2 cooled (lab environment)	EM Cooled (lab environment)	EM Cooled (field environment)
^{241}AM 59 keV	410	450	550
^{57}Co 122 keV	523	570	720

[FWHM (eV) with amplifier shaping time of 4 μs]

Table 1.

Isotopic Measurement Performance[5]

Results of analysis of one hour measurement of PIDIE#5 reference standard using MGA_2 code. Data was taken with a LN2-cooled LEPS and portable electro-mechanically cooled LEGe detectors.

	LEPS (FWHM 534 eV @ 122 keV)		LEGe_PCC (FWHM 723 eV @ 122keV)	
	Weight Percent	% Error	Weight Percent	% Error
^{238}Pu	0.1303	1.75	0.1235	1.49
^{239}Pu	75.46	0.29	75.51	0.23
^{240}Pu	21.56	0.91	21.57	0.71
^{241}Pu	2.001	0.76	1.962	0.54
^{242}Pu	0.8494	(10)	0.8334	(10)
^{241}Am	1.872	0.98	1.848	0.71

Table 2.

The results in the table above indicate that there is no significant impact on the isotopic analysis results from using the cryo-cooled detector.

ONGOING WORK

To widen the practical domain of application for this technology, the cost of long-life expectancy electro-mechanical cryo-coolers and their supporting electronics must be reduced. This is being pursued through ongoing LLNL development and through commercialization efforts. We will continue development of verification analysis software, such as our NELA[6] or PU600[8] codes, or advanced analysis software such as *MGA++* [1,3] that facilitates unattended operation.

Development of different detector configurations are under development or being considered. Integration of the driver/controller electronics into the detector/cooler package is desirable but will require a VLSI implemetation of the current electronics. Integration of the multi-channel analyzer into the detector/cooler package is also being pursued. Towards this end we are evaluating the LANL M^3CA. From the experience in optimizing the active vibration control for the LEGe and the preliminary work on the COAX HPGe, there is substantial engineering effort remaining in perfecting generalized electromechanically cooled germanium detectors.

Sampling conditions and shielding constraints for transportable applications need improved peak-to-compton ratios. Towards this end we are considering composite configurations using co-cooled HPGe and BGO detectors in a Compton suppression configuration.

SUMMARY

Our electro-mechanically cooled HPGe detector can operate for extended periods and at a high enough performance level to allow analysis of the 100 keV regions by MGA and MGAU. This broadens the practicality of high-resolution x- and -ray spectrometry into new safeguards, non-proliferation, arms-control, environmental and emergency response applications. The applicability will broaden further with reductions in size, weight and cost that should occur as a result of commercialization.

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